THE LOST ART OF REGENERATION

Look again at classic regenerative receivers and their importance in radio history, and build these modernized, transistorized versions

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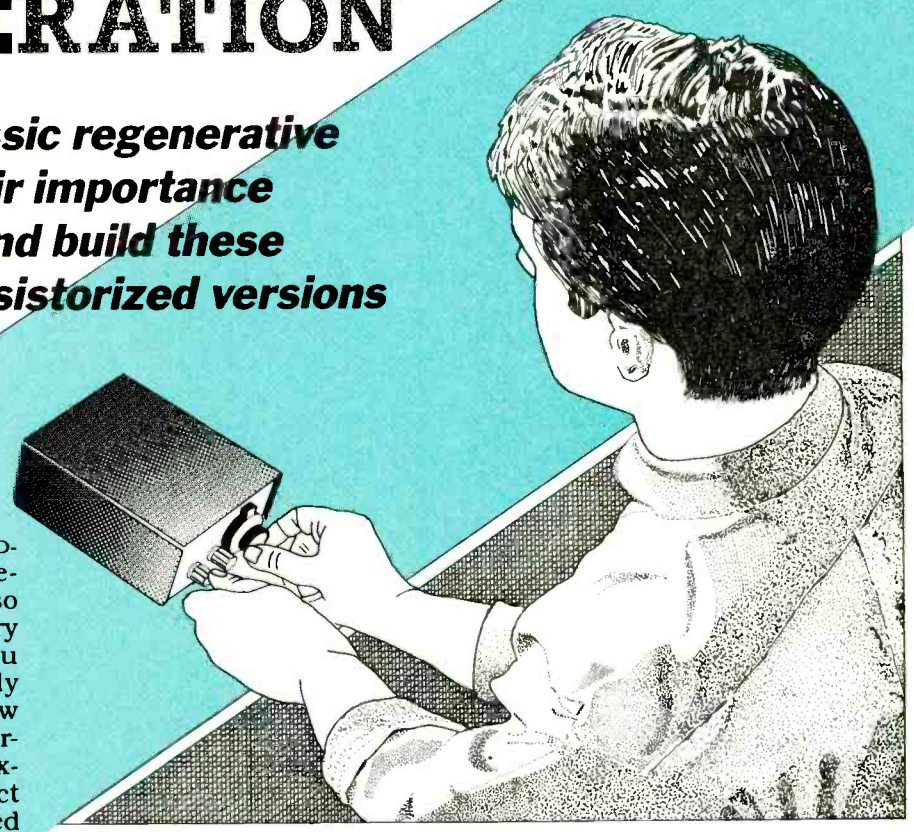

IT IS NOT MUCH FUN TO BUILD A MODern superheterodyne radio receiver these days because so much of the receiving circuitry is within a few ICs. Even if you do build one, you probably won't learn much about how they work—there is little opportunity to experiment and explore. Moreover, you can expect that the cost of parts will exceed the price of a radio at your local drug store. Nevertheless, educators agree that the best way to "get in touch" with the history of radio and enjoy electronics is to start by building a radio receiver from scratch.

This article will return you to those "thrilling days of yesteryear" when almost anyone with an interest in radio could make his own receiver. It will retrace one of the important "roots" of modern electronics—regeneration or positive feedback. The schematics presented here are based on key circuits that were invented by geniuses whose names are only vaguely familiar to most people today.

The four regenerative detector receiver circuits discussed here were designed to give anyone from a novice to an expert "hands on" experience in building circuits that hold an important place in the history of radio communications. Transistors and ICs have replaced the vacuum tubes of the original circuits so you won't have to deal with 120-volt power. These "redesigns" have also minimized the number of "antique" components required.

This article differs from a typical **Electronics Now** "build-it" article—it does not contain parts placement diagrams nor does it contain complete parts lists. This means that if you want to build some or all of these circuits you'll have to be a bit more resourceful. However, the names of several companies offering the "hard-to-get" parts are included in the article.

You should also know that, although the performance of these modernized versions of classic circuits is quite good, skill and patience are needed to get the most out of them. Also some post construction adjustments are called for.

Back in the 1920s and 1930s radio receivers were simple. If you did not want to buy one (they were expensive in those days), all you needed was a handful of parts, wire, solder, and wooden bread board. With a few hours of hand crafting, you could be listening to shortwave or your local AM station.

In those days radio fans were likely to know a lot more about the contributions of the great radio pioneers like Hertz, Fleming, Marconi, and Armstrong. These days their names are rarely mentioned in classrooms because the study of their accomplishments has been crowded out by such modern subjects as digital electronics, signal processing, and computer programming.

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Radio-receiver history

Prior to the development of the vacuum tube, the most common radio circuit was the *crystal set* whose schematic is shown in Fig. 1-*a*. It was found that some natural minerals such as silicon and galena (lead-sulfide) had the ability to rectify current. Electromagnetic waves that intercepted the antenna caused a voltage to be developed across coil L1 between the antenna and ground. That voltage caused a current to flow through crystal D1 and the headphones on the positive half cycle.

When current flowed through the circuit, capacitor C2 was charged. When the polarity reversed, however, there was no current flow through the crystal because of its rectification property. During this half of the cycle, the capacitor discharged through the headphones. Figure 1-*b* shows an audio-frequency wave, Fig. 1-*c* illustrates an audio-modulated radio frequency wave, and Fig. 1-*d* represents a demodulated (detected) wave. The headphone diaphragms followed the audio-frequency wave to produce an audible signal.

Homemade versions of this circuit typically included a lump of galena fastened to a board along with a spring-wire contact called the "cat's whisker." One end of the brass wire was sharpened to point and pressed into the galena crystal. Together these parts formed the diode detector. (The modern Schottky diode also has a metal-to-semiconductor contact.)

A crystal set was easy to make, and the parts were inexpensive. However, the catch was that finding the right contact spot on the crystal with a pointed cat's whisker was likely to be a frustrating experience. Some probing around was necessary to find a location where rectification (detection) would be performed. Moreover, if you wanted the set to work, there had to be a radio station nearby that transmitted a signal strong enough to forward-bias the crystal "diode."

In those early days some hobbyists used Quaker oatmeal boxes as coil forms, and even rolled their own capacitors from the foil-covered paper found in cigarette packs. The antenna was usually about a 100-foot length of bare copper wire strung out the window, suspended from glass insulators. A length of copper pipe was hammered into the earth below the window as a ground connection.

The diode vacuum tube, a simple two-element rectifier, offered little advantage over any of the crystal detectors—it still could not amplify the incoming signal (see Fig. 2). Thus a tube diode circuit still needed a strong signal to detect, and it also it needed power to heat its filament (the early cathode).

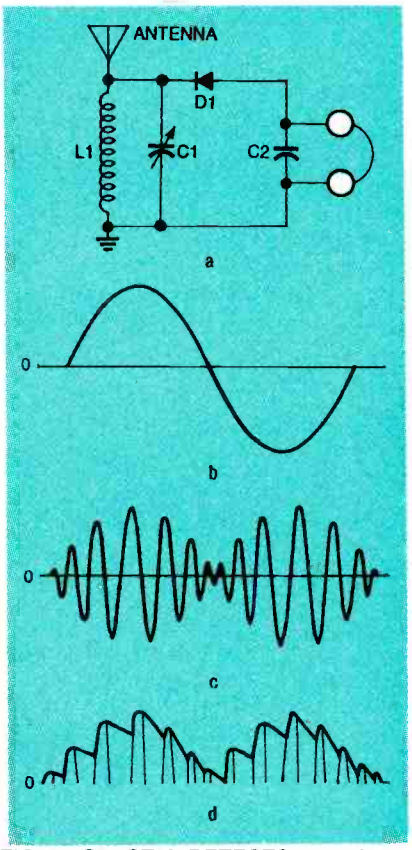

FIG. 1—CRYSTAL DETECTOR receiver with headphones (*a*), audio-frequency signal (*b*), modulated signal (*c*), and demodulated wave (*d*).

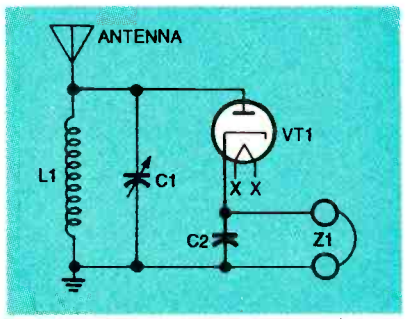

FIG. 2—VACUUM-TUBE DETECTOR receiver.

The great leap forward in receivers occurred with the introduction of the triode vacuum tube. A small voltage variation on the triode's grid caused a large variation in the plate current, providing signal amplification. To receive undistorted signals, the triode amplifier-detector had to be operated on the linear portion of its characteristic curve; thus it needed a bias to put it at the tube's *operating point*. The input signal then caused the total grid voltage to vary above and below the bias value.

The *grid-leak detector* circuit shown in Fig. 3. was one of the early schemes for obtaining the necessary bias. In this circuit, the grid and cathode act as a diode. When an input voltage was applied to the grid, current flowed from the cathode to the grid through grid-leak resistor R1.

A voltage was then developed across the grid leak which provided a bias. The greater the input signal, the more the bias. This caused the voltage between the grid and cathode to vary with the input signal level. As a result, current flowing in the plate circuit was demodulated, and that signal could be heard with a headset.

The simple grid-leak-detector circuit required two power sources—a "B" battery for plate voltage and an "A" battery for the cathode heater combination. This was only one of several possible ways to develop a bias.

The operation of the triode electron tube has similarities to the operation of the N-type bipolar junction transistor (BJT). The cathode is analogous to the emitter, the grid to the base, and the plate to the collector. However, the triode more closely resembles the junction field-effect transistor (JFET). Here the cathode is analogous to the source, the grid to the gate, and the plate to the drain.

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The substitution of JFETs or BJTs for the tubes in the original circuits permits the use of 9-volt transistor batteries as power sources, and generally results in performance that is better than that of tube circuits.

The tuned inductive-capacitive (LC) "tank" circuit in the receivers shown so far permitted discrimination between desired and undesired signals. Figure 4 is a simplified schematic for a tuned radio frequency (TRF) circuit with grid-leak detection. The voltage induced in the antenna caused a current to flow through the primary coil L1 of the radio frequency transformer. A voltage was induced in the secondary coil L2, which was tuned by variable capacitor C1 to resonance at the desired station frequency.

When the resonant frequency was reached, the voltage across L2 increased while the voltages from all other frequencies were reduced. Thus the detector operated most efficiently at the *tuned* frequency.

However, a principal drawback of the resonant tank circuit in the earlier crystal or diode detector receivers is that their detectors robbed energy from their input circuits. This occurred because their operation depended on rectifying the voltage induced in the secondary circuit. The unbuffed "loading" caused by crystal or diode detectors decreased the selectivity or sharpness (Q) of receiver tuning.

While the triode's gain improved the circuit's sensitivity and its buffering relieved the tuned circuit from headphone loading, the overall performance was still poor. Adding more than one stage of RF amplification ahead of the detector did little to improve that performance.

Regenerative detector

In 1914, a gifted radio engineer, Edwin H. Armstrong, discovered that by feeding a portion of the amplified signal in the plate circuit of a triode detector back into the grid circuit, there would be a significant increase in amplification.

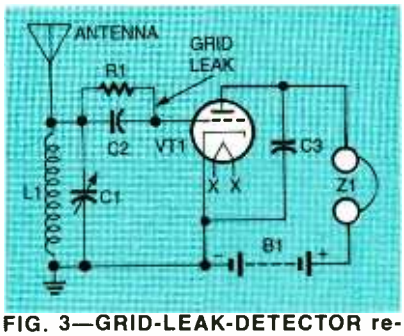

FIG. 3—GRID-LEAK-DETECTOR receiver.

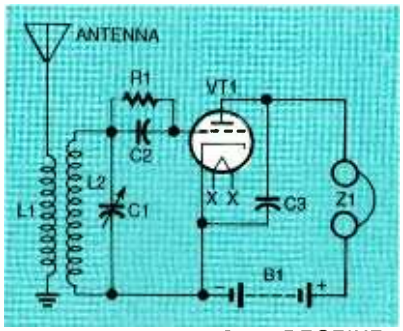

FIG. 4—TUNED-CIRCUIT RECEIVER with grid-leak detection.

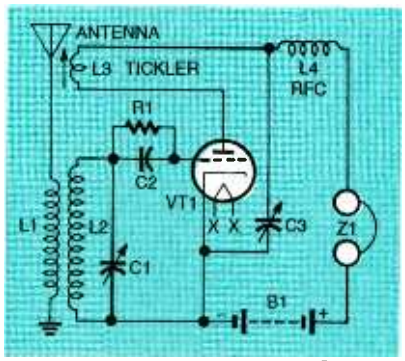

FIG. 5—REGENERATIVE RECEIVER with grid-leak detection.

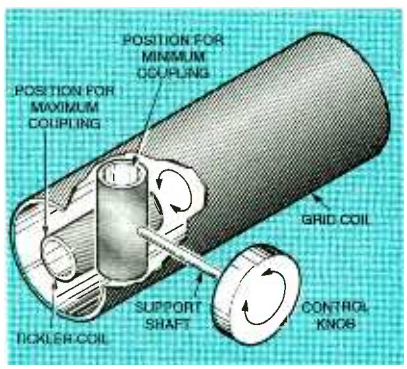

FIG. 6—VARIABLE TICKLER COIL used in early regenerative receivers.

The circuit shown in Fig. 5 is a modern version of Armstrong's original schematic for his regenerative receiver. There was no standard schematic symbol for a vacuum tube.

A regenerative detector is basically a grid-leak detector in which a portion of the output signal is fed back to the tuned input circuit *in phase* with the input signal. The in-phase feedback lowers the resistance of the tuned input circuit, therefore raising its Q. This feedback also substantially increases the strength of input signals at or near the resonant frequency of the tuned circuit. As a result, both the amplification and selectivity of the stage are raised, especially for weak input signals.

The amplified signal in the plate circuit flows through tickler coil L3, which induces an increased current flow through the secondary coil L2. This increases the signal at the grid, causing an even greater signal at the plate. The input signal is therefore repetitively reamplified providing very high single-stage amplification.

If enough of this energy were fed back into the grid circuit, the circuit would oscillate. This is not surprising: Remove the symbols for the antenna, coil L1, and the headphones, and you have a schematic for an *Armstrong oscillator.*

To prevent the receiver from becoming an unwanted oscillator, Armstrong invented a way to control the amount of positive feedback or regeneration. He did this by rotating the tickler coil L3 within the grid coil L2, as shown in Fig. 6. Coil L3 was mounted on a shaft at right angles to the axis of coil L2. (The shaft projects through the front panel of the radio, and a control knob is attached.)

When the knob is turned so that the two coils are in the same plane, maximum feedback is obtained. When the tickler coil is at right angles to the grid coil, feedback is minimum. By carefully rotating the tickler knob, the right amount of regeneration can be found.

This scheme fell into disfavor when receivers with interchangeable coils for several frequency ranges were introduced. The rotating tickler was also bulky and difficult to manufac-

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ture, and the signal was detuned as regeneration was increased. However, it was soon discovered that regeneration could be also be controlled by substituting a variable capacitor for plate-bypass capacitor C3 shown in Fig. 5.

With this so-called "throttle condenser" in the circuit, the listener could simply remove two coils and plug in two alternatives to obtain a different range of broadcast frequencies. The fixed tickler with the right number of turns replaced variable tickler L3 within L2, permitting both L1 and L2 to be exchanged for another set.

The throttle condenser was able to transition the receiver more smoothly into oscillation than the rotating tickler, and regeneration had only a slight effect on tuning. Unfortunately, a second variable capacitor took up more space in the receiver and added to its cost.

However, it was found that varying the plate voltage was a simpler way to control regeneration. Figure 7 is a simplified schematic for a resistive-controlled regenerative detector. It was cheaper than earlier methods and resulted in only slight detuning. Tickler coil L3 was mounted permanently in a fixed position on the same coil form

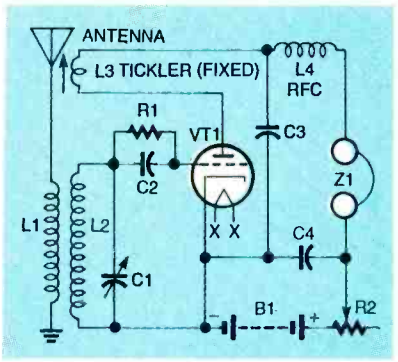

FIG. 7—VARIABLE-RESISTOR-controlled regenerative receiver.

as grid coil L2, and a fixed capacitor bypasses the plate. In this way, plate voltage (and regeneration) is controlled by varying the resistance with panel-mounted control potentiometer R2. Capacitor C4, across the battery, smoothes any sudden changes in plate voltage.

Regeneration principles

While the power gain of a tube or transistor is fixed, the voltage gain of a regenerative detector will approach infinity as it nears self-oscillation. Regeneration introduces a negative resistance into a circuit. Because the circuit's selectivity or "Q" is equal to its net reactance divided by its net resistance, the circuit's selectivity is increased with gain when regeneration is introduced.

When regeneration is below self-oscillation, the circuit's negative resistance (produced by regeneration) is less than its fixed positive resistance. In this condition, regeneration has the effect of providing a stable increase in both gain and selectivity.

With more regeneration, a very dynamic region is reached, just at the threshold of self-oscillation. Here, the circuit's negative and positive resistances near equality. In this nonlinear operating region, minute changes in input level or circuit voltage produce very large (nonlinear) changes in output level.

The exact "balance" point between stable and unstable regeneration (when the circuits net resistance is zero) can never be achieved; even the smallest amount of random noise will eventually build up enough to drive the circuit into sustained self-oscillation.

As regeneration is increased further, a strange "click" will be heard in the headphones. This indicates that the circuit has reached the negative-resistance transition point beyond which free oscillations will occur. If regeneration is increased beyond the oscillation starting point,

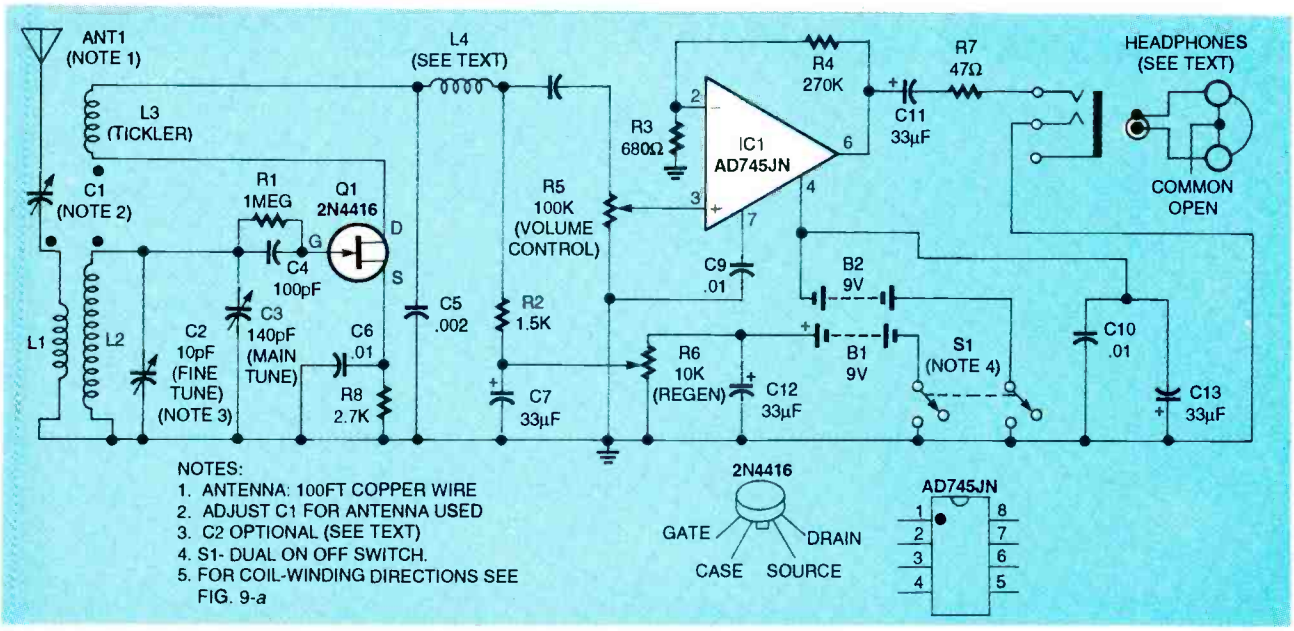

FIG. 8—REGENERATIVE SHORTWAVE receiver with JFET tuning and op-amp amplification. Frequency range is 6 to 17 MHz.

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secondary oscillations at a lower frequency are generated. These oscillations tend to suppress or "quench" the main oscillation under certain conditions of input signal level and regeneration. This effect is called *super regeneration.*

Another property of a regenerative detector receiver is its ability to detect single sideband and frequency-modulated (FM) as well as amplitude-modulated (AM) signals. The single sideband signals are transmitted without a carrier; the carrier is restored in the regenerative detector by setting the regeneration threshold just above the level for free oscillation.

The listener's ability to adjust the effective "Q" of the circuit allows a regenerative circuit to detect the amplitude versus frequency slope of an FM signal. Therefore, a regenerative detector circuit can be a single-stage universal detector in a receiver.

Shortwave receivers

Figure 8 is the schematic for a modern regenerative receiver with a frequency range of 6 to 17 MHz. A 2N4416 junction field-effect transistor (JFET) detector replaces the triode tube, and an AD745JN low-noise BiFET operational amplifier acts as the audio amplifier. A change in drain voltage alters the JFET's transconductance (and therefore gain), permitting the regeneration of the circuit to be controlled easily.

The amplitude-modulated signal from the antenna is coupled to coil L1 through variable capacitor C1 whose value determines the coupling and antenna loading of the detector. Because C1 sets antenna coupling, its optimum value will depend on the length of the antenna selected and the capacitance of the antenna. A 100-foot antenna was used with the prototype.

Coils L1, L2, and L3 are wound on the same form, so the antenna signal developed in L1 is inductively coupled to L2. Capacitors C2 and C3, together with L2, form a resonant tank circuit that determines the receiver's tuned frequency. JFET Q1, a Motorola 2N4416, together with resistor R1 and capacitor C4 detect the amplitude of the incoming signal.

The JFET gate, serving as a diode detector, charges capacitor C4. The amplified drain signal is then coupled back to Q1's gate by tickler winding L3 and is repeatedly re-amplified. Regeneration is controlled by potentiometer R6, which adjusts the supply voltage applied to Q1 and thus its transconductance.

The detected audio output passes through the low-pass filter formed by capacitor C5 and radio-frequency choke (RFC) L4. This filter removes the radio-frequency component and allows only the audio signal to pass. That signal is AC-coupled to volume-control potentiometer R5, and then is amplified by operational amplifier IC1.

An operational amplifier is not a normal audio output stage, but for this receiver it is ideal. The Analog Devices AD745JN (IC1), packaged in an 8-pin DIP, provides an audio gain of 400. (It has a low-current noise of 6.9 femtoamperes per hertz and 20-MHz gain-bandwidth product.) It replaces two or three stages of audio amplification and an output transformer.

The low harmonic distortion and 30-milliampere output current of the AD745JN permits it to drive 32-ohm Sony "Walkman" headphones commonly used with personal stereos. at high-volume levels with low dis-

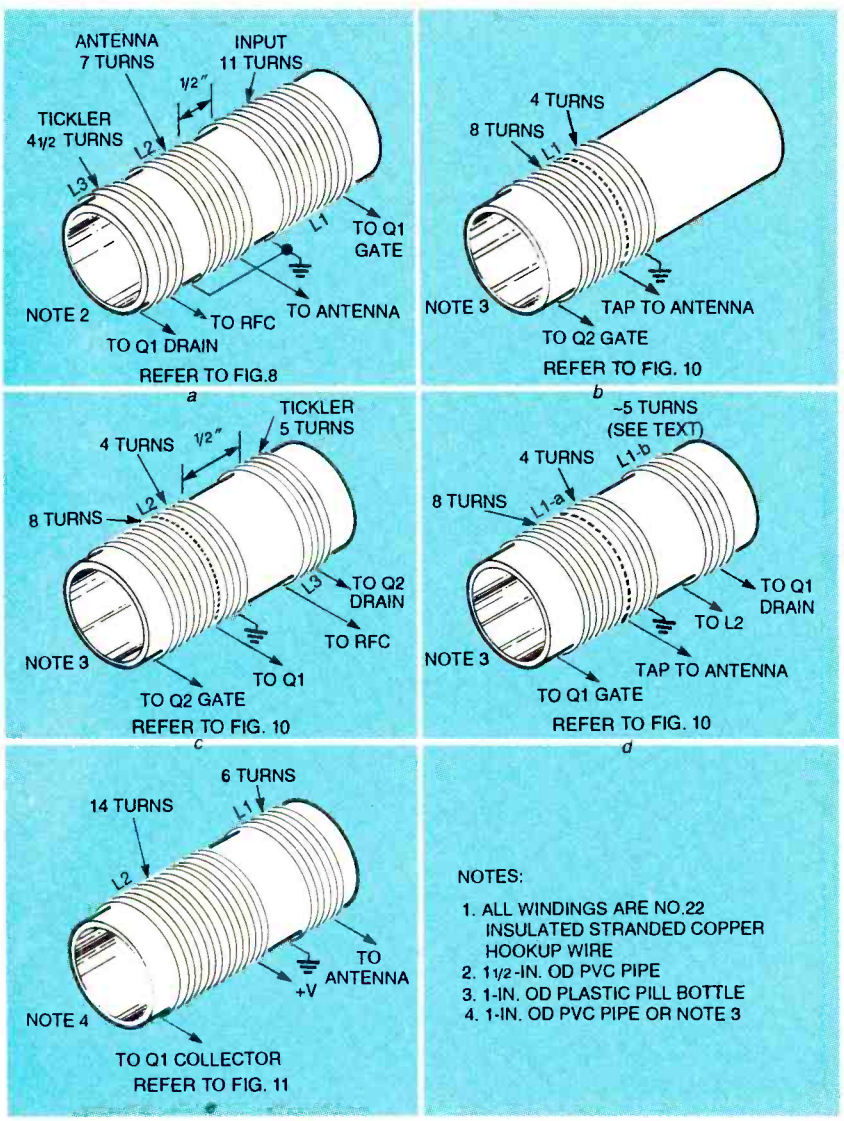

FIG. 9—COIL-WINDING DIAGRAMS for the four regenerative receivers.

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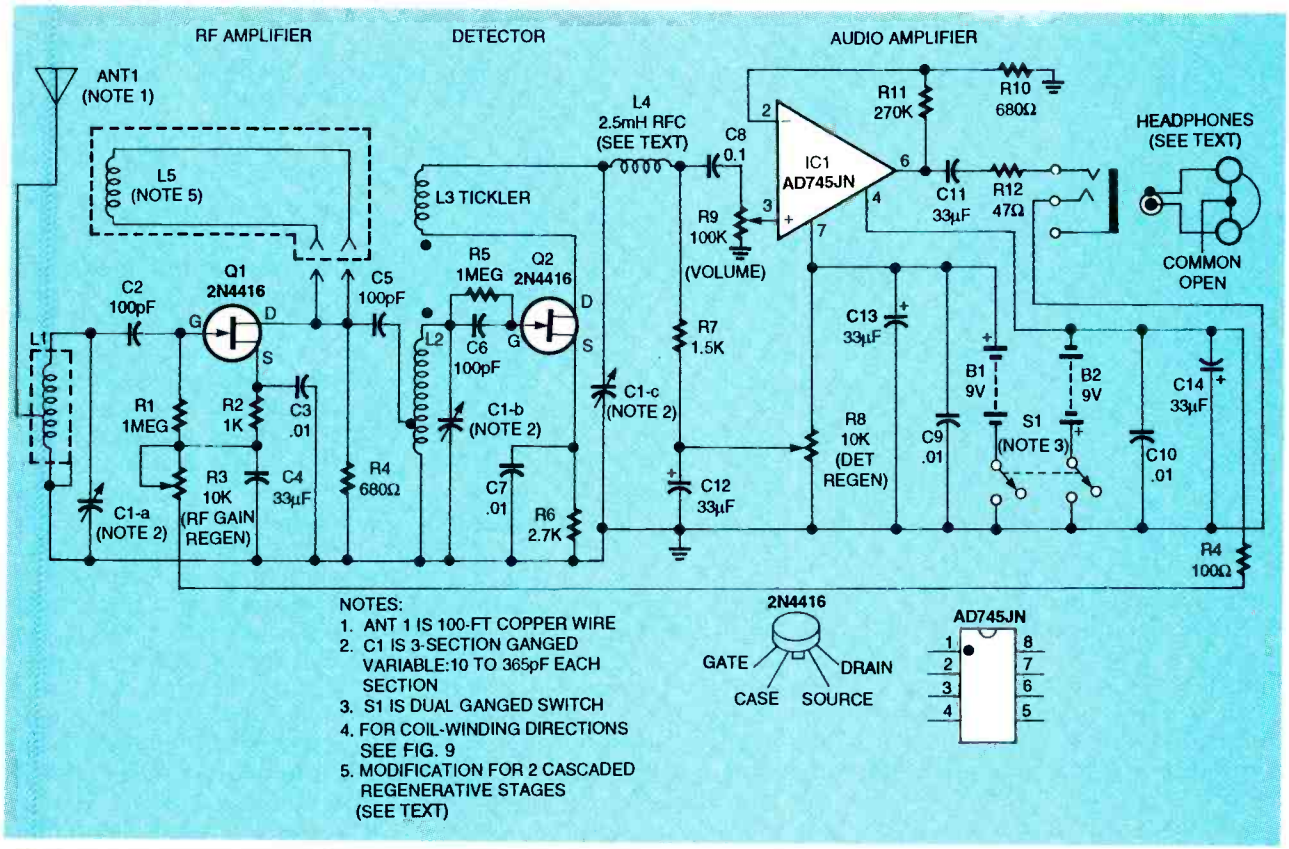

FIG. 10—REGENERATIVE SHORTWAVE RECEIVER with "throttling" capacitor," two JFETs, and an op-amp. An additional coil that adds a second regenerative stage is shown in the dotted box.

tortion. In this circuit, the headphones are series-connected, and their common terminal is floating. This wiring scheme doubles the headphone's impedance to about 64 ohms, making them much easier for the receiver to drive.

The excellent sound quality of this receiver will quickly become evident if you tune to such shortwave stations as BBC London which broadcasts music as well as voice. If a high-fidelity output is not desired, a 0.01 microfarad capacitor can be placed across volume control R5 to attenuate high frequencies.

The optimum number of turns on the tickler winding for a smooth transition into oscillation was found by trial and error. Coil-winding information is given in Fig. 9-*a*. (Figure 9 conains all the coil winding data needed to build the circuits described in this article). Too many turns will cause the circuit to break into free oscillation, making receiver tuning difficult; too few will restrict positive feedback, and receiver sensitivity will suffer.

The main tuning coil for this receiver is wound on a 3-inch length of 1.5-inch outside diameter PVC pipe. Refer to the "Coil winding" section near the end of this article for useful suggestions in coil winding.

PARTS SUPPLIERS

Air-variable tuning capacitors, transformers and miscellaneous components can be purchased from:

- **Antique Electronics Supply, 6221 S. Maple Ave. Temple AZ 85283.**
- **Fair Radio Sales Co. P.O. Box 1105, 1016 E. Eureka St. Lima, OH 45802**
- **Ocean State Electronics, P.O. Box 1458, 6 Industrial Drive, Westerly, RI 02891**

Vernier dials are available from Ocean State Electronics.

The Analog Devices AD745JN operational amplifier and the Motorola 2N4416 JFET can be purchased from any stocking branch of Newark Electronics and many other distributors.

This shortwave receiver was designed to be easy to build. With the exception of the air-dielectric variable capacitors, all of the components are readily available from electronics mail-order houses or retail stores. The two variable capacitors can be purchased from the suppliers whose names and addresses are given in the Source List. The estimated price for all the components is about $20. Stereo headphones add another $7 to $10.

There is nothing critical about the radio-frequency choke (RFC) for this receiver. You can buy a 2.5 microhenry RFC or make your own by winding several layers of turns of No. 30 AWG magnet wire around the entire length of a 470-kilohm, 1-watt, molded carbon composition (or carbon thick-film) resistor. Solder the wire ends to the resistor's leads.

Two 9-volt batteries power this receiver. It draws about 10 milliamperes from the positive battery and 8 milliamperes from the negative battery. The measured sensitivity of this receiver (50-ohm termination, 30% modulated carrier) is approxi-

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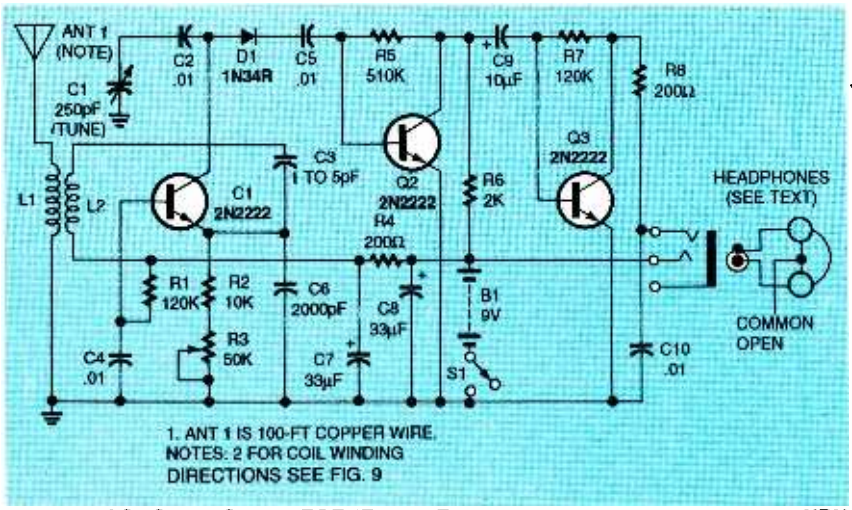

FIG. 11—ECONOMY MODEL REGENERATIVE shortwave receiver based on three NPN transistors.

mately 40 microvolts.

The optional fine-tuning capacitor shown in Fig. 8 can be omitted if you choose to use a vernier dial for operating variable capacitor C3. The author's prototype for this shortwave receiver was built on an aluminum chassis with two side panels. The circuitry was point-to-point wired on a section of prepunched circuit board measuring about 2½ × 2½ inches, with a ground plane on one side. It was mounted on standoffs to the base of the chassis. The potentiometers, tuning dial, jacks, and terminals were mounted on the side walls. The two-9-volt batteries were snapped into clips attached to the side walls.

To operate the receiver, connect the antenna and ground to the set, back the regeneration control knob to the position for minimum regeneration, and turn on the power. With the volume control set in mid position, advance the regeneration control until a click is heard in the headphones.

Tune the receiver until a station is found, and again adjust the regeneration control knob, this time to a point just below oscillation. (There will be an audible howl if the receiver is oscillating when tuned to a station.) If the detector does not oscillate, check the wiring carefully. If the wiring agrees with the schematic, reverse the leads to the tickler winding.

The highest sensitivity and selectivity will be achieved if the receiver is operated at a point just below the threshold of oscillation. The regeneration control must be readjusted each time the receiver frequency is changed. Use one hand for tuning and the other for adjusting regeneration. Here are some tuning hints:

- If a station is being received with adequate volume, a decrease in regeneration will improve the sound quality.
- If more than one station is being received, and they cannot be separated by tuning, an increase in regeneration will provide more selectivity.
- The adjustment of capacitor C1 is important for receiver operation because it adjusts the loading the antenna presents to the detector. For best selectivity, coupling should be just enough to allow the detector to self-oscillate at the low end of its tuning range.
- Increasing the capacitance of C1 loads the detector. This will prevent free oscillation and detune the receiver slightly rather than let it oscillate. (With less capacitance, the detector will oscillate intermittently as the signal level varies.)
- To avoid annoying oscillations, adjust C1 for its highest capacitance. This effectively provides automatic gain control (AGC). While it simplifies tuning, it also reduces receiver selectivity.

In general, for a 100-foot antenna, C1 should be set so that it provides about a third of its total capacitance (30 picofarads). If the antenna length is shorter, capacitance should be 50 to 100 picofarads.

Regenerative negatives

The regenerative receiver of Fig. 8 has its drawbacks. When receiving weak signals, the detector can self-oscillate if the regeneration level is too low to amplify the received signal satisfactorily. As a result, strong signals are amplified significantly with pronounced selectivity, while weak signals receive much less amplification.

When two received signals are close in frequency, it might be difficult to separate the weaker signal from the stronger one, and an audio "whine" occurs. In addition, "dead spots" are encountered as the receiver is tuned across the band because the antenna goes in and out of resonance as receiver frequency is varied. When the antenna is at resonance, it absorbs energy from the detector and loads it down, thus preventing regeneration.

Probably the most annoying characteristic of the simple regenerative receiver is that if its detector free-oscillates, it radiates a signal from the receiving antenna at its tuned frequency. Because the antenna is also tuned to this frequency, it becomes a very efficient radiator.

Therefore, despite the fact that the JFET detector produces only a 10 milliwatt output, the generation of radio

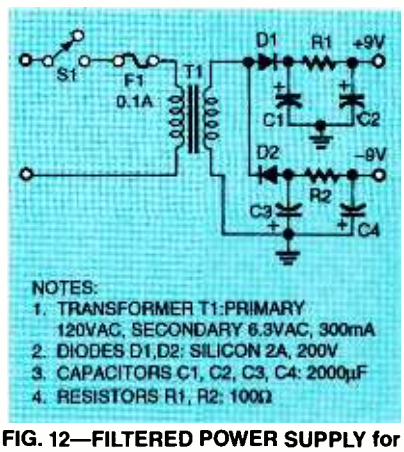

FIG. 12—FILTERED POWER SUPPLY for the transistorized regenerative receiver circuits.

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interference must be avoided. With the circuit of Fig. 8, the best way to prevent the detector from oscillating is to adjust the input coupling with variable capacitor C1 so that the detector never quite breaks into oscillation.

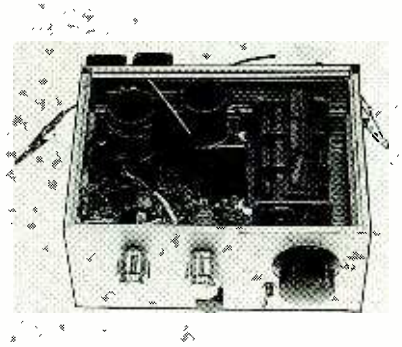
Throttle condenser

The JFET regenerative shortwave receiver circuit in Fig. 10 overcomes many of the drawbacks inherent in the Fig. 8 circuit. It includes a stage of RF amplification that provides about 30 dB of isolation between the detector and the antenna. It substantially improves the sensitivity to better than 0.5 microvolt over most of its operating range, makes some improvement in selectivity, and eliminates antenna "dead spots" caused by antenna resonance effects.

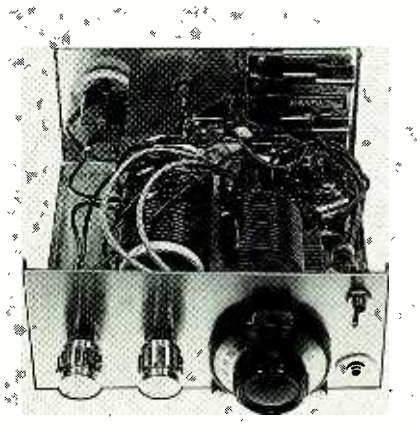
Resistors R1 and R2 set the bias level for RF amplifier Q1. The output of Q1 is coupled to the input of detector Q2 with a 100 picofarad capacitor and a tap on coil L2. This avoids excessive detector loading. Transistor Q1 is powered from the negative battery, while Q2 is powered from the positive battery. This balances the current drain from each battery so that both batteries will be discharged at the same rate.

Potentiometer R3 varies the negative supply voltage that, in turn, varies the RF gain and the signal level applied to Q2. To keep the signal-to-noise ratio high, set detector regeneration control potentiometer R8 near midscale. This allows high RF gain to be adjusted before self-oscillation begins. Resistor R4 and capacitor C4 decouple the power supply between the RF and output stages.

Refer to Fig. 10 and notice that the coils for this receiver (Figs. 9-*b* and 9-*c*) are wound on 1-inch diameter plastic pill containers. The author's prototype was point-to-point wired on perforated universal circuit board with a ground plane on one side measuring 6 ×4½ inches that fit in a 6½-inch ×5 ×3-inch high metal case. Again, as in the Fig. 8 receiver, the manual



REGENERATIVE SHORTWAVE receiver. Note the shield between the RF and detectors.



THIS SENSITIVE AND SELECTIVE receiver was built with a vernier dial for improved tuning accuracy.

controls with knobs, batteries, and headphone jack were mounted on the walls of the metal case.

Unfortunately, the additional gain of the RF stage makes it more difficult to maintain circuit stability. One way to overcome this is to be sure to connect the frame of the multigang tuning capacitor directly to ground with screws rather than relying on a length of wire sandwiched between it and the chassis ground.

Connect the antenna directly to the tap on L1. Connect the gate of Q1, which is AC-coupled by C2, to the top of L1. To maintain its stability, solder a shield made from a small piece of copper-clad circuit board vertically between the RF and detector coils. This prevents strong detector signals from being fed back to the RF stage.

An innovative feature of this circuit is its *tracking throttler* capacitor. In a typical regenerative receiver, feedback or regeneration control must be constantly readjusted as the frequency is varied. However, one section of a three-gang tuning capacitor in this circuit forms a throttling condenser that helps to compensate for higher regeneration levels as the received frequency is increased.

The tracking of regeneration versus the received signal is not precise because the inductance of the tickler coil is less than that of the main tuning coils, while the capacitor values of both are equal. Here a compromise was introduced: additional turns were added to the tickler for better tracking, but the presence of a tickler with the same number of turns as the tuning coils would provide too much feedback. This excessive feedback would, in-turn, require the gain of Q2 to be reduced almost to cutoff, making regeneration difficult to control.

Cascaded regeneration

Two or more cascaded regenerative circuits will significantly increase overall receiver selectivity. The regenerative receiver in Fig. 10 can be modified to make both the RF and detector stages regenerative by adding a second tickler coil, L5, as shown in the inset of Fig. 10. Open the connection between the drain of Q1 and the junction between R4 and C5, and connect the coil shown as Fig. 9-*d* in the coil widing guide. One-inch diameter pill bottles were also used as the forms for this coil. Coils L2 and L3 remain the same.

For the highest selectivity and sensitivity, it is important that both regenerative stages oscillate at the same time. "Regenerative tracking" can be accomplished with just the right number of turns on coil L5-a. (The ≈ symbol indicates that from four to six turns might be required.) Nevertheless, to set both stages for continuous simultaneous oscillation over a useful frequency range, two separate regeneration controls are required: one for the detector and one for the RF stage.

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Figure 12-*a* shows a typical passive *bass* tone-control network, and Figs. 12-*b* through 12-*d* show the equivalent of this circuit when control potentiometer R3 is set to its maximum *boost*, maximum *cut*, and *flat* positions, respectively. Capacitors C1 and C2 are effectively open circuited when the frequency is at its lowest bass value. It can be seen from Fig. 12-*b* that the *boost* circuit is equivalent to a voltage divider formed by dividing 10 kilohms by 101 kilohms. This arrangement results in a low resistive value of about 100 ohms that only slightly attenuates bass signals.

The Fig. 12-*c* *cut* circuit, by contrast, has a voltage divider equal to 110 kilohms divided by a 1 kilohm which gives a signal attenuation of about 40 dB. Finally, in Fig. 12-*d* when potentiometer R3 is set to the FLAT position, it will have 90 kilohms of resistance above the wiper and 10 kilohms below it.

This circuit resistance value is equal to 100 kilohms divided by 11 kilohms. It gives a signal attenuation of about 20 dB at all frequencies. As a result, the circuit gives a maximum bass boost of about 20 dB or *cut* relative to the *flat* signals.

Figure 13 shows a typical passive *treble* tone-control network together with its equivalent circuits under maximum *boost*, maximum *cut*, and *flat* operating conditions. This circuit also provides about 20 dB of signal attenuation when potentiometer R3 is in the *flat* position, and it gives maximum treble *boost* or *cut* values of about 20 dB relative to its *flat* performance.

Finally, Fig. 14 shows how the Fig. 12-*a* and 13-*a* schematics can be combined to make a complete bass and treble tone control network. The 10-kilohm resistor R5 has been added to minimize unwanted interaction between the two connected circuit sections. The input to this network can be taken from the circuit's volume control, and its output can be fed to the input of the power amplifier.

Active tone controls

A tone-control network can be included in the feedback path of a transistor amplifier so that the system will have an overall signal gain (rather than attenuation) when its controls are in the *flat* position. These networks can be simplified versions of the basic circuit shown in Fig. 14. Figure 15 is the schematic for an active tone-control circuit.

A comparision of Figs. 15 and 12 will reveal that the BASS control section of Fig. 15 is a simplified version of Fig. 12-*a*. It can be seen that the two capacitors C1 and C2 of Fig. 12-*a* have been replaced by the single 0.039μF capacitor C2 of Fig. 15. Similarly, the *treble* section is a simplified version of Fig. 13-*a*, with resistors R1 and R2 eliminated. Resistors R3 and R4 balance the performance of the two sections of the Fig. 15 control circuit.

An audio mixer

A multichannel audio mixer is an attractive modification that can be added to the volume/tone-control section of an audio amplifier. This mixer permits several different audio signals to be mixed together to form a single composite output signal. This modification will be of value if, for example, you want to hear the front-door buzzer or the sounds of a baby crying in a child's room while you listening to music.

Figure 16 is the schematic for a three-channel audio mixer that will provide an overall gain of one between the output and each input channel. Each input channel includes a single 0.1μF capacitor and a 100-kilohm resistor, to provide an input impedance of 100 kilohms. The number of input channels to this audio mixer can be increased by adding more capacitors and resistors with the same values as C1 and R1.

The mixer should be located between the output of the tone-control circuitry and the input to the power amplifier. One input should be taken from the output of the tone-control circuit, and the other inputs should either be grounded or taken from the desired source. Ω

REGENERATION

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This modification of Fig. 10 will result in a significant improvement in selectivity and some increase in sensitivity, but it involves a tradeoff. It will perform as well, if not better, than most modern superheterodyne receivers. However, there is a catch. If the RF stage is permitted to self-oscillate, it will radiate its signal from the antenna causing unwanted and illegal transmission, and you lose its principal benefit.

The detector could be set so that it oscillates first, but that will reduce the receiver's overall selectivity. Also, the tracking throttler capacitor is less effective now, and the receiver will need more frequent regeneration adjustment during tuning.

Low-cost receiver

Low cost and availability of components were important considerations in the "modern" regenerative receivers presented here. Nevertheless, the shortwave receiver in Fig. 11 is a "true" economy model. It offers a frequency range of 5.5 to 12 MHz. The prototype receiver was built with about $8 worth of parts (less headphones). While its sensitivity is good, its selectivity and stability are not up to the standards of the receivers in Figs. 8 and 10.

The first thing that you'll notice in examining Fig. 11 is that bipolar NPN transistors have replaced the more expensive JFETs and op-amps. Transistor Q1 is part of a regenerative RF amplifier that provides high gain. The output of germanium detector diode D1 directly drives a two- transistor audio amplifier. (A germanium diode was selected because its forward bias voltage—about half that of a silicon diode—gives the receiver increased sensitivity.)

The author's prototype was point-to-point wired on a 3½-inch square of copper-clad circuit board. This was mounted

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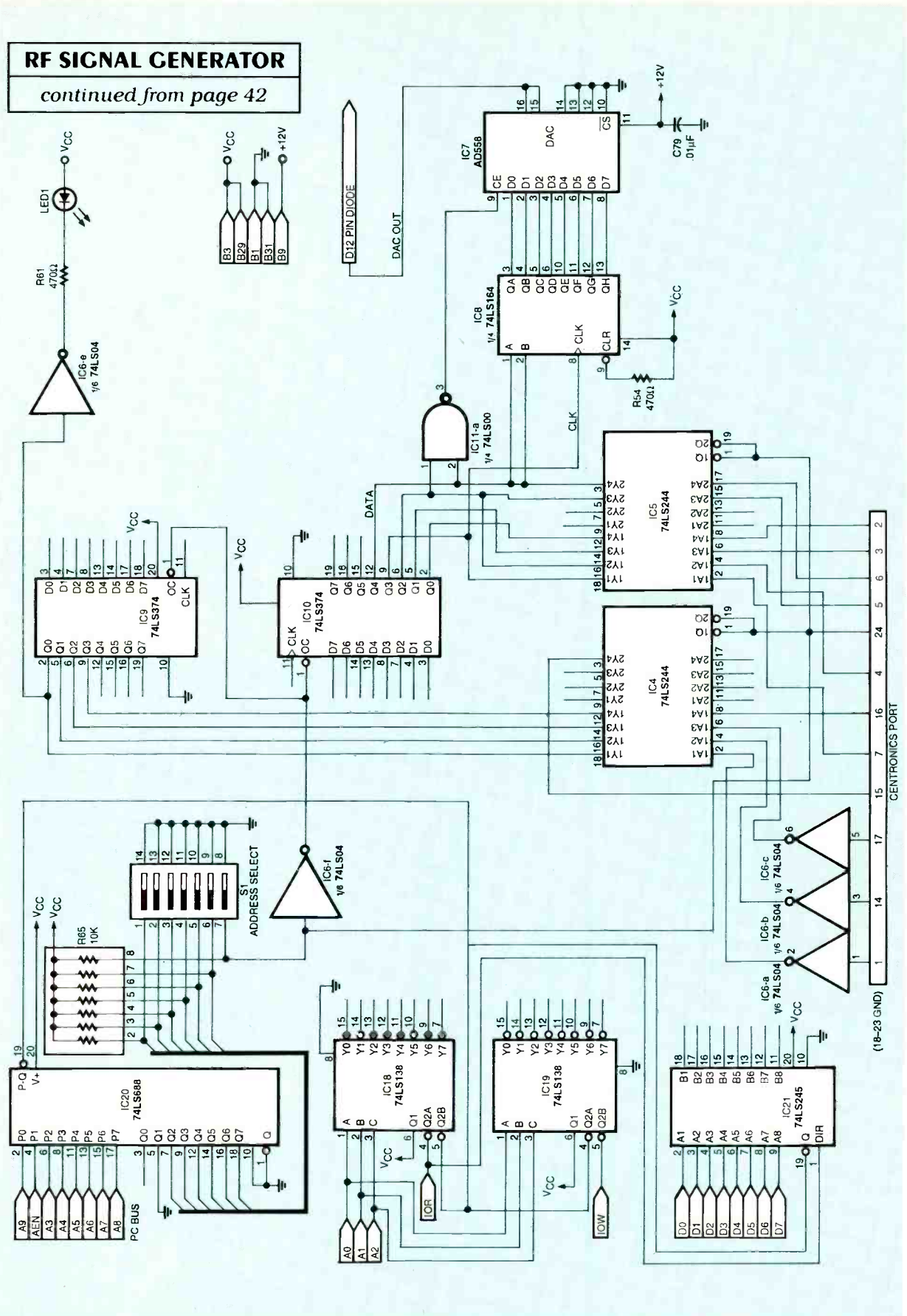

FIG. 13—THE PC-BUS INTERFACE comprises an address/strobe decoder made up of a 74688 (IC20) and two 74138s (IC18 and IC19). The PC data bus is bidirectionally buffered by the 74245 (IC21).

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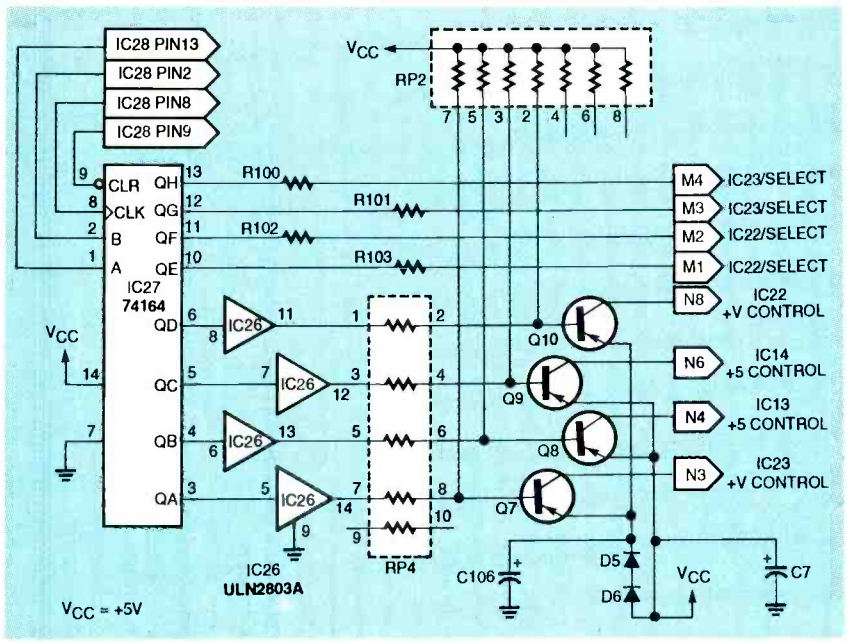

FIG. 14—TWO 74164s (IC27 AND IC28) convert a serial data stream to 16-bit parallel words for the control register.

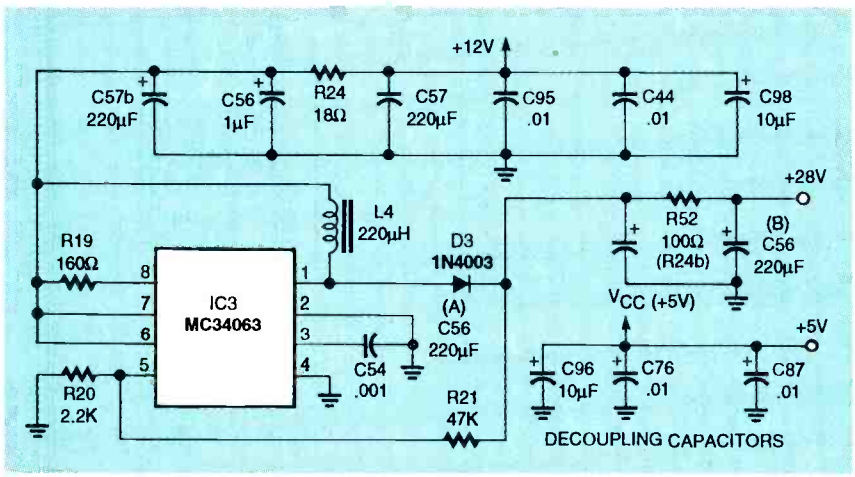

FIG. 15—THE MC34063A +12- TO 28-VOLT CONVERTER provides the higher voltage needed to drive the VCO across its full range.

available on the *Electronics Now BBS*, as part of a ZIP file called TG2000.ZIP.

The TG2000.EXE program contains a menu that allows the user to configure and control the generator. A complete user manual is also contained in the TG2000.ZIP file, so only the highlights will be covered here.

Before using the TG2000 software, you must choose the interface, and possibly the address where the generator will reside on the PC bus. Select the SETUP item from the main menu to configure the software for the chosen address/interface. The setup information is stored in a configuration.

Once the setup operation is complete, you can select either linear or log sweeps and the modulation function. The linear sweep has a constant step size for the entire band of the instrument. The log sweep increases its step size by a factor of two every time it crosses a band boundary. Both sweep functions sweep from a user-defined starting frequency to a user-defined stopping frequency. Sweep rate can be controlled by the DELAY entry.

The other modulation function is a frequency toggle. Two user-defined frequencies are toggled back and forth at a user-defined rate controlled by DELAY. This function can simulate FSK modulation, commonly used for digital data transmission.

Three diagnostic functions are available: Blink, Bitroll, and DAC Ramp. Blink will verify interface operation by toggling all output lines at a 1-Hz rate. Bitroll will debug the 16-bit control register. An alternating pattern of ones and zeros is sent to the 74164s. This results in a square wave at each control bit. DAC Ramp commands the DAC to produce a ramp voltage that will permit any missing codes to be spotted with a scope.

Next month's article will cover the building and and test of the TG2000. Ω

ORDERING INFORMATION

Note: The following items are available from DKD Instruments, 1406 Parkhurst St., Simi Valley, CA 93065. (805) 581-5771:

- **TG2000 kit—$775.00**
- **TG2000 assembled and tested—$1100.00**

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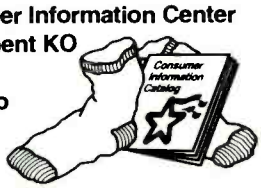

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